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Agro-Ecological Assessment of Soil Quality of a River Watershed in the Niger Delta Region of Nigeria

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Abstract
The chemical properties of the degraded soil around River Ediene watershed in the Niger Delta Region of Nigeria were analyzed to determine the soil quality level of the forested mosaic. This was assessed by taking 9 samples from different points around the watershed. Each sample was tested for percentage concentration of organic matter, nitrogen, calcium, phosphorus, potassium, magnesium, sodium, aluminum and soil pH. Reconnaissance survey preceded the 9 sites soil sample collection. The sampling points were made 50 metres apart from the bank of the river, designated as A, B, C. The result of the analysis shows that the soil around River Ediene watershed has an organic matter content of 0.9%, magnesium content of 0.085 Meq Mg/100g, and 0.52 Meq C_a/100g of calcium, percentage aluminum of 0.077% (770 ppm), Phosphorus content of 17.23ppm, nitrogen of 0.025%. It also contained 0.016 Meq Na/100g of sodium, 4.63ppm potassium and the soil pH was 6. 17. It was therefore concluded that the soil is not of good quality as the values were lower than the standard soil requirement and needs to be raised for arable farming
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Keywords: watershed, soil quality, Niger Delta Region, soil fertility, agro-ecological, River Ediene

1. Introduction

According to Larson and Pierce (1991) soil quality is the capacity of a specific kind of soil to function for its intended use, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain water and air quality, and support human health and habitation. Soils of good quality gives clean air and water, bountiful crops and forests, production rangeland, diverse wildlife and beautiful landscape (Karlen et al. 1997). The new and emerging strategies of soil quality assessment use a large number of soil function dependent indicators (Bone et al. 2010). This study is, therefore, an attempt to carry out soil quality assessment in the area to provide information on the condition of the soil. This is done to improve the soil use by the local population and to ensure suitable management practices for the maintenance of the soil quality. This goal is plausible, especially in the humid tropics, where there is pronounced spatial and temporal variability in quality of soils due to variable land uses (Onweremadu et al. 2006 and Onweremadu 2007).

According to Doran and Parkin (1994), the interest of farmers in soil quality may have been encouraged by their desire to examine and validate the management practices on their own farm. Such qualitative soil must contain biological elements that are key to ecosystem function within land use boundaries (Zeiss *et al*. 2003), to sustain biological productivity of soil, maintain the quality of surrounding air and water environments, as well as promote plant, animal and human health, (Doran and Zeiss 2000). The soil must have the capacity to function, within managed or natural ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and habitation.

Soil quality has consistently evolved with an increase in the understanding of soils and soil quality attributes. Soil quality cannot be measured directly but through indicators which soil properties that are sensitive to changes in management (Andrews and Cambardella 2004). Soil quality needed to help farmers understand the chain of causes and effects that link farm decisions to ultimate productivity indicators are and health of plants and animals. Andrews and Carroll (2001) maintained that soil quality depends on the defined purpose, for example, agricultural use; where attention is paid to plant and animal productivity in cultivated soils (Doran, 1996), as opposed to urban soils (Idowu and Van, 2007). The basic assessment of soil quality is necessary to evaluate the degradation status and changing trends following different land use and small holder management interventions (Lal and Stewart 1995).

In Asia, adverse effects on soil quality arise from nutrient imbalance in soil, excessive fertilization, soil pollution and soil loss processes (Zhang *et al*. 1996; Hedlund *et al.* 2003). In Africa, three quarters of farm lands are severely degraded (Eswaran *et al*. 1997). As a result, Africa cannot produce enough food to keep pace with its needs and per capital food consumption. Food production is declining, largely due to loss or decrease in soil quality. This decrease in the soil quality, according to Karlen, *et al*.,(1997) can also affect the maintenance of the quality of surrounding air and water environments (Lal, *et al*. 1997).

The dynamic quality of soil can affect its sustainability and productivity and is being controlled by chemical, physical, and biological components and their interactions (Parpendick and Parr 1992). According to Riley (2001), indicators vary according to the location and the level of sophistication of measurements. Biological indicators of soil quality have been reported as critically important by Abawi and Widmer (2003) because soil quality is strongly influenced by microbial mediation process such as nutrient cycling, nutrient capacity, and aggregate stability. Of particular importance is the identification of those components that rapidly respond to changes in soil quality (Romig *et al*. 1995). Biological indicators of soil quality that are commonly measured include soil organic matter and mineralizable nitrogen which play a key role in soil function, soil quality determination, water holding capacity and susceptibility of soil to degradation and soil organic matter which serves as a sink to atmospheric carbon IV oxide (Giller and Cadisch, 1997, Lal *et al*. 1997).

Understanding how nutrient resources vary across landscape has become the focal point of much ecological research (Benning and Seastedt 1995). Onweremadu (2007) argues that the spatial variation of soil quality and eventual productivity is affected in many ways by the varying socio-economic activities such are farming, sand dredging, compaction of soil, and other anthropogenic activities such as washing of clothes, digging of holes to catch crabs and other soil dwelling creatures. Investigation of soil quality under intensive land-use and fast economic development is a major challenge for sustainable resource use in the developing world (Doran *et al.* 1996). This study, therefore, investigates the extent of variation and level of quality of soils around the River Ediene watershed in southeastern Nigeria.

2. Materials and Methods

2.1 Brief description of the study area

The River Ediene watershed is located in Abak Local Government Area of Akwa Ibom State of southeastern Nigeria. It lies between Longitudes 07^0 47' E and 07^0 47' E and latitudes 04^0 58' N and 04^0 58' N. Soils of the study area are derived from Coastal Plains Sands (known as Benin Formation) of the Oligocene – Miocene era. It is within the humid tropics, characterized by annual rainfall range of 2250 – 3500 mm and daily temperature are generally high with a mean of 32^0C in all seasons (Njoku 2006, Onweremadu 2007). Degraded rainforest vegetation dominates the site which has a sloping physiography into the River Ediene in Abak Local Government Area of Akwa Ibom State of Southeastern Nigeria.

The people of the area are mainly small scale peasant, arable farmers who cultivate water leaves, pepper, vegetable leaves on the landscape for commercial purposes and consumption. The soil, due to rising population pressure, is becoming increasingly fragile. This is currently promoting deforestation accelerated erosion and loss of fertility around the site. There are also fisherman and sand miners who fish and dredge sand as their source of livelihood. Given these activities which expectedly degrade the soil, it is important the soil quality be assessed to determine causes of the low productivity the extent of soil depletion in the study area.

2.2 Field activities and sampling

The site was surveyed, distances measured and geo-referenced using the handheld Global Positioning System (GPS) receiver (Garmin Ltd, Kansas, USA) during the month of July in 2010. Dominant plants in the region included oil palm tree (*Elaeis guineensis*), bitter Kola (*Garcinia cola*), oil bean tree (*Pentaclethra macrophyllum*), Gmelina (*Gmelina arborea*), sour sop (*Annona muricata*), locust tree (*Robinia pseudocacia*) dominate the landscape (Onweremadu 2007). Personal communication with the land users around the site showed that the forest was over 50 years.

The sampling was carried with the following materials: soil auger, meter rule, plaster containers, cello tape, handheld Global Positioning System, field book and stakes. The sample collection points were measured 50 meters apart from the bank of the river at points A, B and C. Three points up the watershed to give a total of 9 soil sampling points. The samples were collected using a calibrated soil auger of 6 cm diameter which was marked up to a depth of 15cm using the meter rule and a nail and then inserted into the soil by turning the handle in a clockwise direction until the marked depth was reached. It was then pulled out to remove the soil. The soil at the tip of the auger was collected into the plastic container. This procedure was repeated for the remaining 8 sampling points. The nine 9 samples were bagged using the black polyethene bags and transported to the Laboratory of the School of Agriculture and Agricultural Technology of the Federal University of Technology. Here, the soil was air dried, crushed and readied for laboratory analyses which were conducted following the techniques of Anderson and Ingram (1993) and Okalebo *et al*. (2002). Sampling precautions include the use of dedicated sampling equipment, labeling of the plastic container before sampling and the collection of samples from the tip of the soil auger. The soil samples were tested for soil pH levels, organic carbon, soil organic matter, calcium and magnesium and phosphorous, soil nitrogen, soil potassium and sodium.

The components of soil in the various data collection sites were determined and presented in the following sections.

3. Results

3.1 **Soil Characteristics and Properties**

Table 1 shows the characteristics of the soil samples in the watershed studied in terms of the pH, nitrogen, phosphorus, aluminum and calcium. The pH was lowest at site A1 with 5.57 and highest at A3 with 6.52. The mean soil pH is 6.17, mean % nitrogen is 0.025, mean phosphorus 17.23ppm, mean aluminum 0.077% (i.e., 770ppm) which is within the desired range of 6.0 to 6.8 for nutrient availability. The soil aluminum content is 770 ppm which is within the range of 500-800. This presents a "medium" rating and above the lower limit of 400 ppm. It is expected that the high aluminum content in the soil will affect plant growth. Thus at this pH, nutrients are more readily available to plants and microbial population in the soil. The highest value of nitrogen in the soil of the study area is at B1 with 0.220, whereas the phosphorus and aluminum showed highest values of 22.5 and 0.48 at C3. The calcium content in the studied soil showed values in the range of 3.00 at A2 and 14.40 at A1. The mean phosphorus content in the soil is 17.23ppm which is lower than the minimum required availability of phosphorus in any good soil, and this signifies that the soil is deficient in phosphorus. This scenario corresponds with the views of Baig (1983) Arshad and Akram (1999) that no area has all the essential factors in the optimum range of plant growth. Thus, all the areas have fertility constraints to plant growth and yield.

In the result of soil analysis, as presented in Table 2, the percentage soil organic matter is 0.9% which is far below the ideal soil organic matter level of 5%. This low organic matter content also gives a signal of low total nitrogen content in the soil. The soil analysis result shows a deficient the amount of percentage nitrogen present in the soil. A low value of percentage nitrogen of 0.025% was available for plants and, this is evident in the low crop yield in the area. In soil of similar characteristics studies recommended the use of *Gliricidia* and *Leucaena* species, a tropical woody legume, for bringing about favourable changes in the soil properties by enhancing soil conservation and fertility regeneration for sustainable production (Hartemink 2004; Schwendener et al, 2005; Vanlauwe *et al*. 2005; WAC, 2006). In a study in Nigeria, (Mensah *et al*. 2007) confirmed that *Gliricidia sepium* is the most widely used tree legume because it has the ability to establish well on acid soils prevalent in the region. Again, in the agroforestry practices in Nigeria, it is used as stakes for yams or climbing beans and left on the farms during the fallow period to enhance soil fertility restoration and regeneration process through nitrogen fixation and high litter production and accumulation (Yamoah and Ay, 1986; Zaharah and Bah, 1999; Elevitch and Francis, 2006). This leads to substantial increases in the amounts of nitrogen, phosphorus, potassium, and calcium in the soil during alley cropping or bush fallow.

In the result of the soil analysis, as presented on Table 2, the organic carbon content of the soil is peak at A2 with 8.42 and lowest at C3 with 4.20. The result actually represents the soil surface characteristics which allow sensitive detection of changes in soil organic matter dynamics and soil fertility (Cadisch *et al*. 1996). The percentage soil organic matter is 0.9% which is far below the ideal soil organic matter of 5%. This low organic matter content also gives a signal of low total nitrogen content in the soil. The mean per cent soil organic content is 0.5 while mean per cent soil organic matter is 0.9.

According to Table 2, only 0.012% of potassium is found to be present in the soil. This value is below the minimum cation saturation potassium, and thus, the soil is said to be deficient of potassium. The value obtained showed that mean ppm of potassium is 4.63ppm while the mean Meq/100g is 0.012 Meq K/100g. This is low compared to the values obtained by Mensah *et al* (2007) in southern Nigeria. The standard values are shown on Figure 1.

The soil analysis reveals that the calcium content is 0.52Meq Ca/100g and magnesium content of 0.085Meq Mg/100g as shown on Tables 3 and 4. Though these values obey the law of Mg: Ca ratio of 1:6, it can be seen that the two elements are present in the soil at a level lower than their optimum cation saturation levels, which is an indicator of the soil's deficiency in magnesium and calcium. This situation is not good for plants growth, though soil fertility requirements varies with plants for better returns from food and fibre crops (Yadav and Swammi 1998).

The soil organic matter in the study area presented the highest value of 1.477% at site C_3, while the lowest of 0.1293% is at site A_2. On the other hand, the soil organic content showed the highest value of 0.8558% at sites C_1 and C_2 just as the lowest value of 0.075% occurred at site A_1. In all, there was wide variation in the values of both the soil organic content and the soil organic matter. This may implies further that soil quality is fragile.

The analysis of the soil sample shows 0.016 Meq Na/100g, which is within the range of 0.005 - 0.03 is ideal for the soil. But unfortunately, this amount does not affect the plants growth as it is not required by plant for its growth and development. It can thus be use advantageously to regulate metabolic activities especially in the absence of potassium

It was also shown that in the study area the mean ppm of sodium is 3.76 ppm, while the mean Meq Na/100g is 0.016 Meq Na/100g (See Table 5). The values range from 0.014 at site A_2 whereas the highest value is 0.019 occurring at sites A_1, C_2 and C_3. The highest ppm of sodium is 4.45 which occurred at A_1, while the lowest value is 3.25 at A_2 and B_1. The sodium standard graph on Figure 1 is the reference for the measurement of sodium content of the soil.

4. Conclusion

The result of the study shows that the soil around River Ediene watershed has an organic matter content of 0.9%, magnesium content of 0.085 Meq Mg/100g, 0.52 Meq C_a/100g of calcium, aluminum of 0.077% (770 ppm), phosphorus content of 17.23ppm, nitrogen 0.025%, 0.016 Meq Na/100g of sodium, 4.63 ppm potassium and soil pH of 6. 17. Based on the results, the soil of River Ediene watershed may not be of good quality. It has low minerals and organic matter content compared to the standards for soil nutrient requirements. To increase the soil quality, the plants nutrient needs should be supplemented with organic fertilizer such as fish emulsion. Besides, the addition of organic matter to the soil is necessary to lead to increase in the nitrogen content of the soil. Conversion of tropical rainforest to grassland provokes a net loss of organic fractions and this is promoted by high rainfall amount, intensity and duration of the study site. With shortening fallow period and increased slash and burn practice, runoff and leaching are encouraged in the region and environs (Williams *et al*. 1997 and Onweremadu 2007). Finally, the watershed should be allowed longer fallow period to help the soil regenerate and regain nutrients.

The values obtained points to the fact that the soil fertility in the area may be dynamic, moving between fertile soils, moderately fertile soils and poor soils. (Corbeels *at el.* 2000; Sharma *et al*. 2005; Handayani *et al.* 2006). In addition, Schmidt *et al.* (1993) reported that land management is the key to increasing the soil fertility beyond the present, inherent levels. This fits with the view expressed by William and Ortiz-Solorio (1981) and Karlen *et al.* (2003) that soil fertility is a human-made technical attribute rather than inherent soil property. The soil fertility challenge of the study area may worsen, and not strongly support arable farming, with rising human and animal population as well as increasing spatial and temporal use of the land in the years ahead.

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Table 1: Soil pH, nitrogen, Phosphorus, Aluminum and Calcium for the study area

pH		Nitrogen		Phosphorus		Aluminum		Calcium	
sample	Value	sample	Value	sample	Value (ppm)	sample	Value (% Al)	sample	Titre value
A_1	5.57	A_1	0.028	A_1	18.8	A_1	0.01	A_1	14.40
A_2	6.08	A_2	0.008	A_2	12.0	A_2	0.01	A_2	3.00
A_3	6.52	A_3	0.012	A_3	14.0	A_3	0.01	A_3	6.20
B_1	6.12	B_1	0.220	B_1	18.4	B_1	0.01	B_1	3.90

B_2	6.12	B_2	0.032	B_2	20.6	B_2	0.02	B_2	5.90
B_3	6.42	B_3	0.012	B_3	16.0	B_3	0.06	B_3	6.20
C_1	6.32	C_1	0.034	C_1	17.6	C_1	0.02	C_1	9.40
C_2	6.16	C_2	0.035	C_2	15.2	C_2	0.08	C_2	10.60
C_3	6.23	C_3	0.038	C_3	22..5	C_3	0.48	C_3	11.80

Table 2: Soil Organic carbon, Calcium Magnesium, Soil Organic Matter and Potassium

Organic Carbon		Cal. Mag (Ca/mg)		Soil Organic Matter			Potassium			
Sample	Titre Value	Sample	Titre Value	Sample	% SOC	% SOM	Samples	Emission from Flame photometer	Ppm K	Meq Na/100g
A_1	5.90	A_1	14.80	A_1	0.58	0.99	A_1	22.9	8.75	0.022
A_2	8.42	A_2	2.60	A_2	0.075	0.1293	A_2	5.4	1.30	0.003
A_3	8.20	A_3	5.90	A_3	0.1197	0.206	A_3	13.2	4.00	0.010
B_1	6.10	B_1	3.90	B_1	0.538	0.927	B_1	8.1	2.13	0.005
B_2	5.50	B_2	6.00	B_2	0.658	1.134	B_2	13.6	4.13	0.010
B_3	8.30	B_3	6.20	B_3	0.0997	0.17	B_3	5.6	1.38	0.004
C_1	4.51	C_1	9.40	C_1	0.8558	1.475	C_1	7.7	2.06	0.005
C_2	4.50	C_2	9.20	C_2	0.8558	1.475	C_2	13.4	4.06	0.010
C_3	4.20	C_3	11.90	C_3	0.857	1.477	C_3	32.7	13.88	0.036
Blank	8.80	Blank	2.20	Blank	0.9177	1.582				

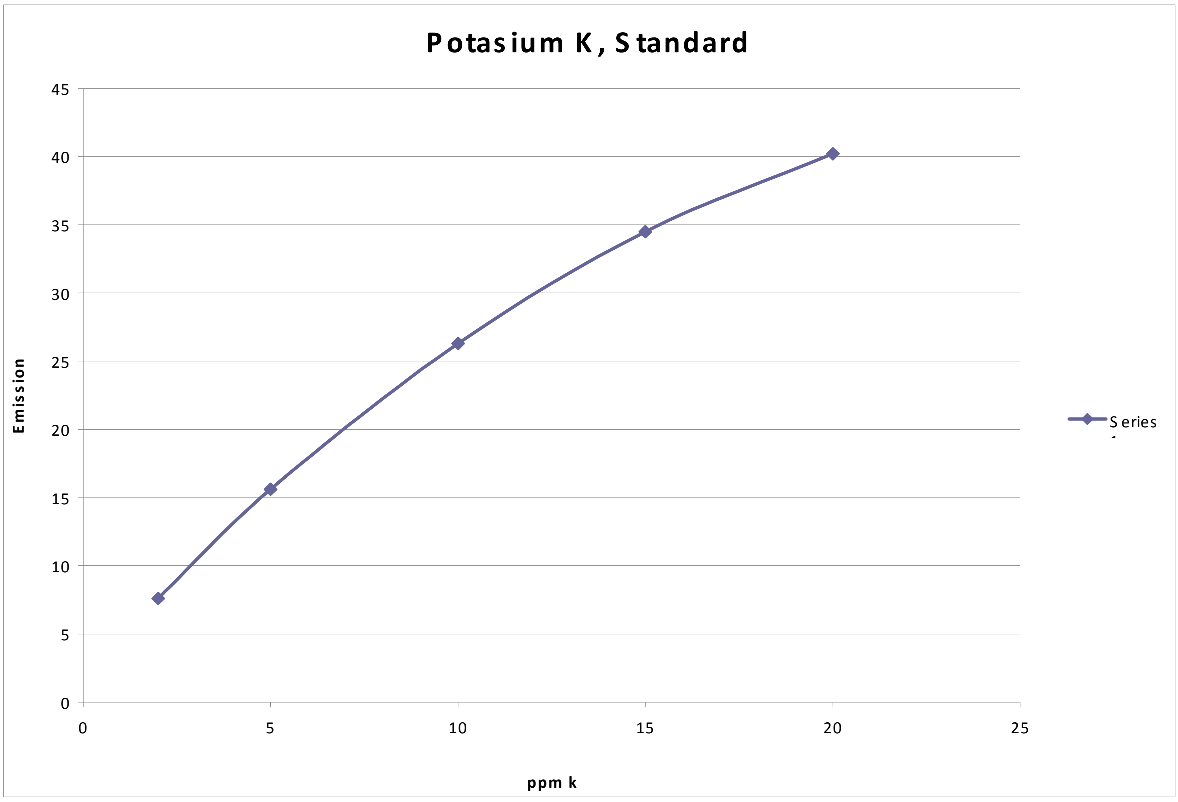

Figure 1: Potassium standard graph

Table 3: Calcium Magnesium (Ca/Mg).

Samples	C_a (ppm)	Mg (ppm)	Meq Ca/100g	Meq Mg/100g
A_1	238	14	1.19	0.117
A_2	8	2	0.04	0.017
A_3	74	0	0.37	0
B_1	28	6	0.14	0.050
B_2	68	8	0.34	0.067
B_3	74	6	0.37	0.050
C_1	138	6	0.69	0.050
C_2	148	14	0.74	0.117
C_3	158	36	0.79	0.300
Average	103.7	10.2 0	0.52	0.085

Table 4**:** Calcium Magnesium (Ca/Mg).

Samples	Ca/Mg (g/kg)	Ca(g/kg)	Mg (g/kg) = Ca/Mg) – Ca
A_1	2.52	2.38	0.14
A_2	0.10	0.08	0.02
A_3	0.74	0.74	-
B_1	0.34	0.28	0.06
B_2	0.76	0.68	0.08
B_3	0.80	0.74	0.06
C_1	1.44	1.38	0.06
C_2	1.62	1.48	0.14
C_3	1.94	1.58	0.36

Table 5: Sodium content of soil in the study area

Samples	Flame photometer reading	Ppm Na	Meq Na/100g
A_1	2.3	4.45	0.019
A_2	1.7	3.25	0.014
A_3	1.9	3.65	0.016
B_1	1.7	3.25	0.014
B_2	2.0	3.85	0.017
B_3	1.8	3.45	0.015
C_1	1.8	3.45	0.015
C_2	2.2	4.25	0.019
C_3	2.2	4.25	0.019

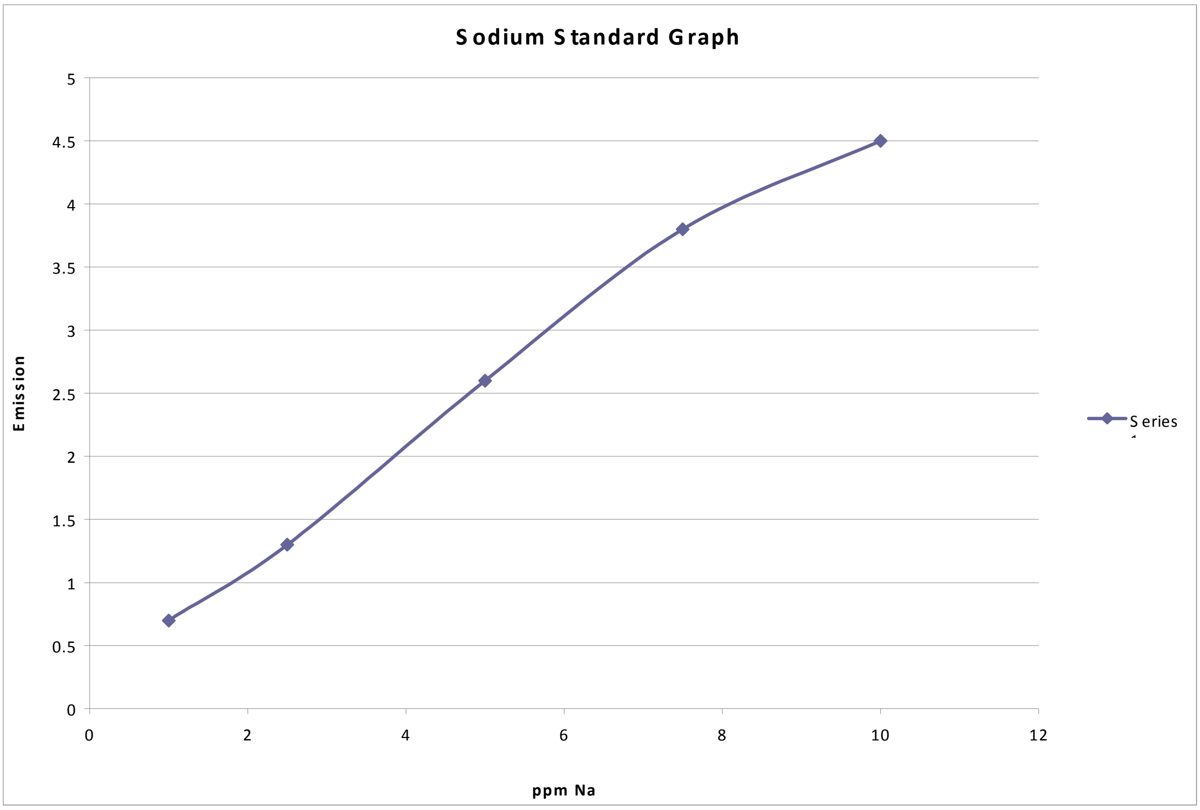

Figure 2: Sodium standard graph